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Warming and Sterilizing Towels by Microwave Irradiation

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A steamed and sterilized towel was easily obtained using a home microwave oven. A small piece of gauze (7 × 7 cm) containing approximately 5×10^8 organisms in 1 mL of saline was rolled up in the moist towel which was wrapped in heat-resistant vinylidene polychloride film (wrap film). *Staphylococcus aureus*, *Pseudomonas aeruginosa* and *Candida albicans* in the towel were completely killed by microwave irradiation for 1 min. When three towels were irradiated simultaneously, it took 2 min for complete killing of the bacteria. In another experiment, the small gauze containing the bacterial suspension was set in a sterile plastic dish and completely dried using filtered air for a period of 3 h. After a 5-min irradiation in a microwave oven, the survival rate of *S. aureus* was 17%. These results indicate that a sterile steamed towel can be obtained by microwave irradiation of a moist towel wrapped in wrap film.

Key words: *Candida albicans;* microwave irradiation; *Pseudomonas aeruginosa*; *Staphylococcus aureus*; sterilization

Dielectric heating by microwave irradiation is well known to have an effect on killing microorganisms (Lund, 1975; Metaxas and Meredith, 1988). Microwave irradiation is used for the sterilization of food products (Chipley, 1980; Fung and Cunningham, 1980; Cross and Fung, 1982; Rosenberg and Bögl, 1987), and medical appliances and materials, such as acrylic resin dentures (Polyzois et al., 1982; Thomas and Webb, 1995), scalpel blades (Rosaspina et al., 1994a, 1994b), polyethylene catheters (Griffith et al., 1993) and plastic tissue culture vessels (Sanborn et al., 1982). The polar compounds in the materials, when exposed to microwave irradiation, generate heat by the collision and friction between molecules. Most microorganisms are killed by the heat generated. Thus, it is important that water is present in the irradiated materials. However, the possibility of nonthermal microwave effects has been proposed (Frölich, 1975; Cope, 1976; Pickard and Rosenbaum, 1978).

In the aging society of Japan, it has become of increasing importance to care for aged persons or bedridden patients. One of the activities of caregivers is the wiping of patients' bodies which requires sterile, comfortably warm towels. In this study, we sterilized towels by microwave irradiation. The opportunistic pathogens, *S. aureus*, *P. aeruginosa* and *C. albicans*, were seeded into the towels, which were then subjected to microwave irradiation. Then, bacteria were cultured in broth or on agar plates to confirm the survival rate. We compared the survival rate of bacteria contained in a small moist gauze with that of bacteria attached to a small dry gauze, following microwave irradiation. The degree of moistness of the towel is discussed.

Materials and Methods

Bacterial strains

The bacterial strains used were *Staphylococcus aureus* IFO12732, *Pseudomonas aeruginosa* B17 and *Candida albicans* JCM1542. All are opportunistic pathogens and were stored in our laboratory. *S. aureus* and *P. aeruginosa* were

Table 1. Decreased moistness of a towel subjected to microwave irradiation

Towel	Amount of water added* (mL)	Microwave irradiation (min)					
		1	2	3	4	5	6
Half-sized towel	0	S	S	D	NT	NT	NT
	30	W	S	S	S	S	S
Regular-sized face towel	0	S	S	S	S	S	S
	50	NT	NT	NT	W	S	S

*A towel was dampened with running water and wrung tightly. Then, a fixed amount of water was added to the towel.
D, relatively dry; NT, not tested; S, suitable for wiping the body; W, dripping wet.

cultured on nutrient agar slants, and *C. albicans* on Sabouraud agar slants.

Preparation of bacterial suspensions

Each bacterium in suitable broth medium was cultured overnight at 37°C with shaking. The bacterial culture was transferred to a sterilized test tube, and centrifuged at 3,000 rpm for 10 min. The precipitate was resuspended in saline at a concentration of approximately 5×10^8/mL. In the case of *C. albicans*, the concentration was approximately 5×10^6/mL.

Microwave irradiation of towels

One milliliter of the bacterial suspension was pipetted onto a small sterilized gauze (7×7 cm), which was rolled up in a moist towel or a half-sized towel. The towel was wrapped in heat-resistant vinylidene polychloride film (wrap film; Saran Wrap, Asahi Kasei Kogyo Co., Ltd., Tokyo, Japan). When three towels were used simultaneously, each towel was wrapped in wrap film, and the three wrapped towels were put side by side on the microwave oven dish. Microwave irradiation (500 W of output power; 2,450 MHz) was performed using a microwave oven (Corona Co., Ltd., Tokyo).

In another experiment, a small gauze containing 1 mL of the bacterial suspension was set in a sterile plastic dish and dried in filtered air for 3 h in a safety cabinet. The dried gauze in the plastic dish was irradiated in the microwave oven.

Enumeration of viable cells

After microwave irradiation, the gauze was transferred from the towel or from the dish into broth (or Sabouraud broth), and rinsed. An aliquot of the broth was serially diluted with saline, and viable cells were enumerated by colony counting. The remainder of the broth was incubated at 37°C without further treatment.

Results

Degree of moistness of towel before and after microwave irradiation

A regular-sized face towel and a half-sized towel were dampened with running water and wrung tightly. The towels were wrapped in wrap film, irradiated at regular intervals, and tested to determine whether they were suitable for wiping the body of an aged person.

In the case of the half-sized towel, the addition of water to the wrung towel was not necessary when a 2-min irradiation was used, but 30 mL of water had to be added for irradiation of 2 min or more (Table 1). The regular-sized towel required no addition of water when 5-min irradiation was used. Thus, in subsequent experiments, no water was added to the half-sized towel for a 2-min microwave irradiation, or to the regular-sized towel for a 3-min irradiation.

Table 2. Bacterial growth in broth or Sabouraud broth after microwave irradiation

Towel	Duration of microwave irradiation (min)	Bacterial growth*		
		S. aureus	*P. aeruginosa*	*C. albicans*
Half-sized towel	0	+	+	+
	1	–	–	–
	2	–	–	–
Regular-sized face towel	0	+	+	+
	1	–	–	–
	2	–	–	–
Three face towels used simultaneously	0	+	+	+
	1	+	+	+
	2	–	–	–
	3	–	–	–

**S. aureus* and *P. aeruginosa* were grown in broth and *C. albicans* was grown in Sabouraud broth.
+, growth was observed; –, no growth was observed.

Survival rate of bacteria in the moistened towel following microwave irradiation

A bacterial suspension was pipetted onto a small piece of gauze which was then rolled up in a towel and subjected to microwave irradiation. Recovery rate of bacteria in the gauze after rolling up in the moist towel was about 35% in two separate experiments (data not shown). When the half-sized or the regular-sized single towel was irradiated for 1 min, no bacteria were recovered from the gauze (Table 2 and Fig. 1). All three types of towels were hot, and of a suitable degree of moistness for wiping the body.

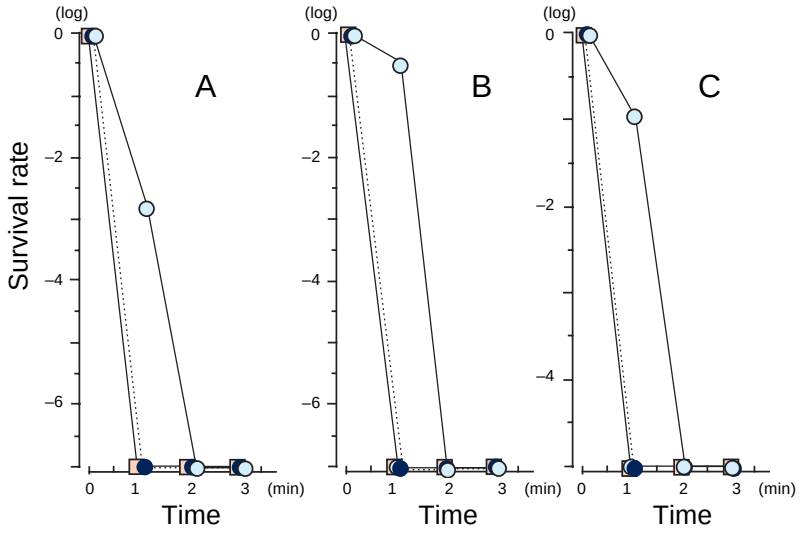

Fig. 1. Lethal effects of microwave irradiation on bacteria in a moist towel. Approximately 5×10^8 organisms (or 5×10^6 organisms in the case of *C. albicans*) in saline were pipetted onto a small gauze, rolled up in a half-sized or regular-sized towel, and then wrapped in wrap film. A half-sized towel (□), a regular-sized towel (●) and three towels simultaneously (○) were irradiated in a domestic microwave oven. **A**: *S. aureus*; **B**: *P. aeruginosa*; **C**: *C. albicans*. Colony counting was performed as described in **Materials and Methods**. Recovery of bacteria in the gauze after rolling up in the moist towel was about 35% (in two separate experiments). The symbols on the transverse axis show that no bacterial growth was observed.

When the *S. aureus*-containing towel was irradiated together with two other towels for 1 min, the towels were warm but not hot, and the survival rate of *S. aureus* was 1.6%. However, no bacteria survived after a 2-min irradiation. The survival rates of *P. aeruginosa* and *C. albicans* in three towels after 1-min irradiation were 33% and 11%, respectively (Fig. 1). The bacteria were completely killed by a 2-min microwave irradiation. Thus, the survival rates of bacteria were dependent on the towel volume. For the effective killing of bacteria a longer microwave irradiation is required as the volume of towels increases.

Survival rate of bacteria in the dried gauze

A small gauze containing an *S. aureus* suspension was dried up in a plastic dish in filter-sterilized air for 3 h. After microwave irradiation at regular intervals, the gauze was transferred into 5 mL of broth followed by serial dilution and colony counting. As shown in Fig. 2, the survival rate of *S. aureus* gradually decreased as the irradiation time increased. However, *S. aureus* survived even after a 5-min irradiation (survival rate, 17%). In contrast, *S. aureus* on the surface of the moist gauze was killed by 1-min irradiation. In another experiment, an aliquot of an *S. aureus* suspension was placed in a sterile plastic dish, dried up in filtered air and irradiated for 5 min. Then, 5 mL of broth was added to the plate, mixed well and transferred to a test tube for incubation overnight at 37°C. The results indicated that viable organisms could be observed even after a 5-min irradiation (data not shown).

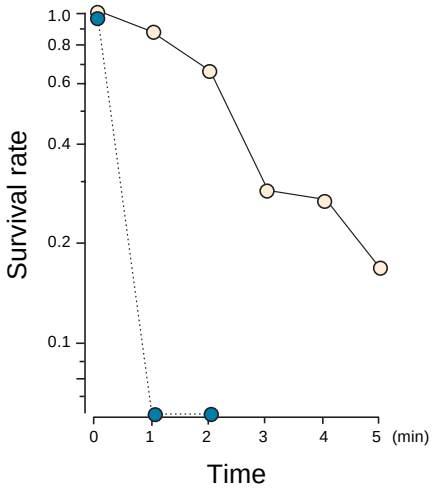

Fig. 2. Survival rate of *S. aureus* in the dried gauze. Approximately 5×10^8 *S. aureus* cells in saline were pipetted onto a small gauze which was set in a sterile plastic dish. The gauze was dried (○) with filtered air for 3 h in a safety cabinet, or not dried (●). Microwave irradiation and colony counting were carried out as described in **Materials and Methods**. The symbols on the transverse axis show that no bacterial growth was observed. The data are typical in the three separate experiments.

The above data and Fig.2 show that the bacteria in the dried condition were not completely killed by microwave irradiation. In both of the cases mentioned above, the plastic dishes, if not moistened, were not hot after a 5-min irradiation.

Discussion

In addition to the thermal effects of microwave irradiation (Coote et al., 1991; Diaz-Cinco and Martinelli, 1991; Fujikawa et al., 1991; Welt et al., 1994), nonthermal effects on inactivation of microorganisms have also been reported (Frölich, 1975; Cope, 1976; Wayland et al., 1977). Kakita and colleagues (1995) analyzed the DNA from microwave-irradiated *Lactobacillus* phage PL-1 by agarose gel electrophoresis, and showed that the phage DNA chain was broken by microwave irradiation. However, they claimed that inactivation of phage PL-1 was due to the heat produced by microwave irradiation.

In this study, a moist towel was wrapped in wrap film, and the heat generated by microwave irradiation effectively killed the microorganisms present in the wrapped towel (Table 2 and Fig. 1). The temperature within the wrapped towel may reach close to 100°C. Thus, it is conceivable that spores of *Bacillus* and *Clostridium* would not be effectively killed by microwave irradiation in our system. Heating by autoclaving (121°C) may be required for the complete killing of spores. When the dry gauze containing bacteria was irradiated for 5 min, the bacteria were not completely killed (Fig. 2). It

is considered that sufficient heat was not generated in the dehydrated gauze by microwave irradiation or that the heat generated may have diffused in the air. However, when a dry towel was irradiated with or without wrapping for 2 to 3 min, it smoked. These findings indicate that towels should be moistened and wrapped for the effective inactivation of microorganisms by microwave irradiation.

Recently, it was reported that many medical instruments, such as catheters (Griffith et al., 1993), acrylic resin dentures (Polyzois, 1995; Thomas and Webb, 1995), stainless-steel scalpel blades (Rosaspina et al., 1994a, 1994b) and plastic tissue culture vessels (Sanborn et al., 1982), are sterilized by microwave irradiation. Our data on the killing of bacteria in towels showed that the dielectric heating of towels by microwave irradiation generates towels suitable for the care of aged persons and bedridden patients. The heating and sterilization of a towel using a domestic microwave oven was achieved using a 1-min irradiation, and a 2-min irradiation when three towels were used simultaneously. Thus, at home and in small hospitals, it is easy to prepare sanitary towels using domestic microwave ovens.

Due to the aging society in Japan, the importance of the care of bedridden patients is gradually increasing. Caregivers should protect aged persons against infection by opportunistic pathogens. There are many opportunistic pathogens present in the environment, such as enterobacteria (*Escherichia coli*, *Klebsiella pneumoniae*, *Serratia*, *Enterobacter*, *Proteus*), gram-negative bacilli (*Pseudomonas*, *Acinetobacter*), *Staphylococcus*, fungi (*Candida albicans*, *Aspergillus*), protozoa (*Pneumocystis carinii*) and viruses (cytomegalovirus, human herpes virus-1 and -2). We tried to inactivate opportunistic pathogens and prepare sterile, comfortably hot towels using a domestic microwave oven.

Methicillin-resistant *S. aureus* (MRSA) has become a major factor in nosocomial infection, and is, together with *P. aeruginosa*, resistant to many antibiotics (Locksley et al., 1982). It is thus reasonable to use sterilized, comfortably hot towels for aged persons and bedridden patients to protect them from decubitus and chronic infection. Our finding that *S. aureus*, *P. aeruginosa* and *C. albicans* when present in a moist towel covered with wrap film, were killed by a 1- or 2-min microwave irradiation, indicates that towels prepared in this manner are sufficiently sanitary to be used for care of aged persons.

References

1 Chipley JR. Effects of microwave irradiation on microorganisms. Adv Appl Microbiol 1980;26: 129–144.

2 Coote PJ, Holyoak CD, Cole MB. Thermal inactivation of *Listeria monocytogenes* during a process simulating temperatures achieved during microwave heating. J Appl Bacteriol 1991;70: 489–494.

3 Cope FW. Superconductivity—a possible mechanism for non-thermal biological effects of microwaves. J Microwave Power 1976;11:267–270.

4 Cross GA, Fung DYC. The effect of microwaves on nutrient value of foods. Crit Rev Food Sci Nutr 1982;16:355–382.

5 Diaz-Cinco M, Martinelli S. The use of microwaves in sterilization. Dairy Food Environ Sanit 1991;11:722–724.

6 Frölich H. The extraordinary dielectric properties of biological materials and the action of enzymes. Proc Natl Acad Sci USA 1975;72: 4211–4215.

7 Fujikawa F, Ushioda H, Kudo Y. Kinetics of *Escherichia coli* destruction by microwave irradiation. Appl Environ Microbiol 1991;58:920–924.

8 Fung DYC, Cunningham FE. Effect of microwaves on microorganisms in foods. J Food Prot 1980;43:641–650.

9 Griffith D, Nacey J, Robinson R, Delahunt B. Microwave sterilization of polyethylene catheters for intermittent self-catheterization. Aust NZ J Surg 1993;63:203–204.

10 Kakita Y, Kashige N, Murata K, Kuroiwa A, Funatsu M, Watanabe K. Inactivation of *Lactobacillus* bacteriophage PL-1 by microwave irradiation. Microbiol Immunol 1995;39:571–576.

11 Locksley RM, Cohen ML, Quinn TC, Tompkins LS, Coyle MB, Kirihara JM, et al. Multiply antibiotic-resistant *Staphylococcus aureus*: introduction, transmission, and evolution of nosocomial infection. Annal Intern Med 1982;97: 317–324.

12 Lund DB. Heat processing. In: Fennema OR, ed. Principles of food science. New York: Marcel Dekker; 1975. p.31–92.

13 Metaxas AC, Meredith RJ. Theoretical aspects

of volumetric heating. In: John AT, Ratcliff G, Platts JR, eds. Industrial microwave heating. London: Peter Peregrinus; 1988. p.70–102.
14 Pickard WF, Rosenbaum FJ. Biological effects of microwaves at the membrane level: two possible athermal electropyhsical mechanisms and a proposed experimental test. Math Biosci 1978;9: 235–253.
15 Polyzois GL, Zissis AJ, Yannikakis SA. The effect of glutalaldehyde and microwave disinfection on some properties of acrylic denture resin. Intern J Prosthodont 1995;8:150–154.
16 Rosaspina S, Salvatorelli G, Anzanel D. The bactericidal effect of microwaves on *Mycobacterium bovis* dried on scalpel blades. J Hosp Infect 1994a;26:45–50.
17 Rosaspina S, Salvatorelli G, Anzanel D, Bovolenta R. Effect of microwave radiation on *Candida albicans.* Microbios 1994b;78:55–59.
18 Rosenberg U, Bögl W. Microwave pasteurization, sterilization, blanching, and pest control in the food industry. Food Technol 1987;41:92–99.
19 Sanborn MR, Wan SK, Buland R. Microwave irradiation of plastic tissue culture vessels for reuse. Appl Environ Microbiol 1982;44:960–964.
20 Thomas CJ, Webb BC. Microwaving of acrylic resin dentures. Eur J Prosthodont Restor Dent 1995;3:179–182.
21 Wayland JR, Brannen JP, Morris ME. On the interdependence of thermal and electromagnetic effects in the response of *Bacillus subtilis* spores to microwave exposure. Radiat Res 1977;71: 251–258.
22 Welt BA, Tong CH, Rossen JL, Lund DB. Effect of microwave radiation on inactivation of *Clostridium* sporogenes (PA 3679) spores. Appl Environ Microbiol 1994;60:482–488.

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